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Changes in the flora of Lobbia Alta, a peak of the Adamello-Presanella Alps (Trento, Italy) between 1935 and 2021

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Abstract

Global warming is causing an enrichment of summit flora worldwide. This article presents the case of a peak in the southeastern Alps (Lobbia Alta, 3,196 m a.s.l., Adamello, Trento, Italy), for which a complete list of tracheophytes dating back to 1935 was available. As this peak is well delimited by glaciers and vertical cliffs, it has been possible to faithfully repeat this floristic inventory. We made three surveys, in 1991, 2006 and 2021, exploring the whole area. It resulted that in 86 years the species present on this peak have tripled, increasing from 17 to 51, with an acceleration in recent years. The biological forms have increased from two to six. The average temperature and the nutritional indexes according to Ellenberg have increased as well. We found that as many as six species reach their elevation record in the Alps on the Lobbia Alta, suggesting that this area is particularly prone to species ascension. Particularly interesting is the discovery of a 35 cm-tall specimen of *Larix decidua* at 3,130 m a.s.l., which seems to be the elevational record of the species.

Keywords

Climate change, flora of Trentino, southeastern Alps, summit flora

Introduction

In the Alps, the climate has warmed by about 1.8 °C since 1880, almost double the global average. Models are especially pessimistic for the southern Alps, where at the end of the current century an increase of more than 4 °C compared to the period

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1981–2010 is expected in a worst-case scenario (Kotlarski et al. 2022). Evidence for the consequent enrichment of the summit vascular flora in the Alps was presented already many years ago (Braun 1913; Braun-Blanquet 1955). More recently, numerous medium- and long-term monitoring activities have confirmed that climate change is causing an upward expansion of species, particularly in the summit areas of the Alps (Hofer 1992; Grabherr et al. 1994; Pauli et al. 2012; Unterluggauer et al. 2016; Lamprecht et al. 2018). A research extended to 302 European peaks has shown that this speed is increasing in each of the nine mountain areas considered, including the Alps (Steinbauer et al. 2018). The upward movement of the species should cause new elevation records, but these have generally received little attention. There is no shared and recognized initiative dedicated to archiving recent elevation records at the Alpine (or European) level. Only some sources highlight elevational records (for example Flora della Valle d'Aosta 2022+; Swiss National Forest Inventory 2022+), but they are limited in terms of territory and/or plant group considered. On the contrary, a large body of historical data is available thanks to the research of elevation records in vogue in the past (e.g., Heer 1885; Vaccari 1901; Reisigl and Pitschmann 1958). Elevational records at alpine level were reported, for example, by Fenaroli (1955). Unfortunately, an updated version of this work is not available.

The aim of this research was to investigate the changes in the summit flora of a peak on the southern slope of the eastern Alps, an area particularly prone to global warming. We also sought to establish whether the plants found there constituted an elevational record.

Materials and methods

Study area description

The Lobbia Alta (3,196 m a.s.l.; 46.1704°N, 10.5674°E; Fig. 1) is a peak located in the Adamello-Presanella Alps in the southern Rhaetian Alps (Adamello-Brenta Natural Park, Trento, Italy). The rock is made up of Tonalite. The average annual temperature is between -2 and -4 °C for the period 1981–2010. Compared to the valley bottoms, the temperature here is growing more rapidly, as shown by the data from the nearby station of Cima Presena (3,015 m a.s.l.), which in the period 1998–2008 saw the average temperature rising by 0.5 °C/year (by 0.7–0.8 °C if only summer temperatures are considered). Annual rainfall amounts to approximately 1,300 mm, with summer maximum and winter minimum (Climatrentino 2022+). The vegetation is typical of the upper part of the alpine belt, very discontinuous, made up, as regards vascular plants, of sparse individuals mostly rooting in rock crevices.

Nino Arietti (Bardolino 1902; Brescia 1979), one of the most important botanists in Brescia, noticed that the Lobbia Alta corresponded to what botanists at the time called the "glacial island" and for this reason, in 1935, he surveyed its flora (Arietti 1936). This prompted us to undertake the survey of the flora of the Lobbia Alta in 1991. As already observed by Arietti (1936), the west side of the Lobbia Alta, covered

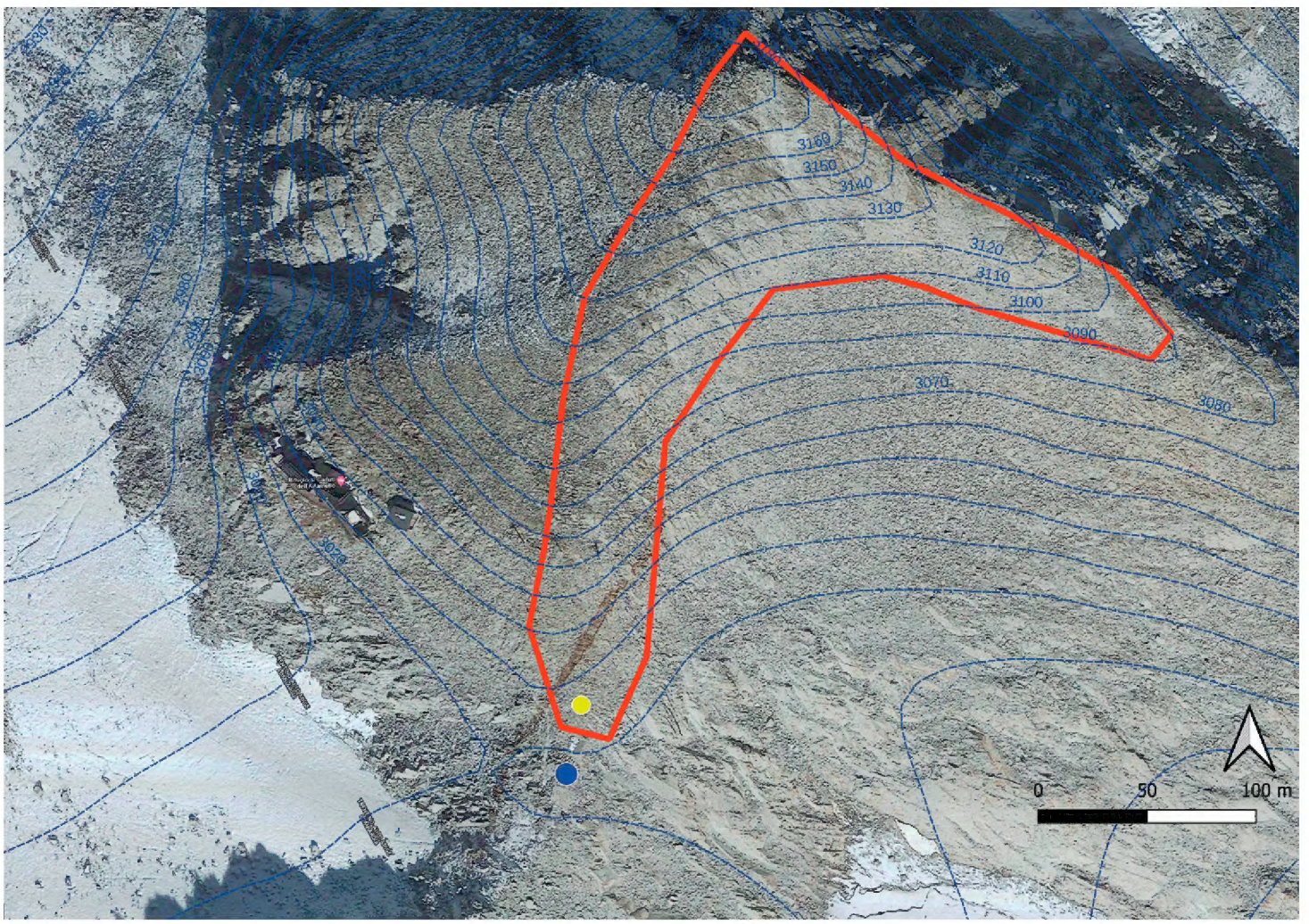

Figure 1. Lobbia Alta (Trento, Italy). In red, delimitation of the study area. The blue dot is the helicopter pad, the yellow one is the altar. On the left is the Rifugio Caduti dell'Adamello. Map data (C) 2015 Google.

with boulders that do not allow the accumulation of humus, is unsuitable for hosting vascular plants. The bedrock emerges on the southern and northern sides, the latter consisting of nearly vertical walls exposed to the north-east and north-west, and not explored due to the evident danger and the unlikelihood of finding plants. The most suitable site for the presence of vascular plants, according also to Arietti (1936), is the south side with an almost perfect southern exposure and an inclination of *ca.* 40°. Here Tonalite outcrops are cracked and dark due to surface weathering caused by cryptogams (mainly lichens) with organic soil present in the cracks, indicating that the area was not covered by perennial snow or ice since a long time. The investigated area, of approximately 2 ha, includes this slope with dark rocks; it starts from the Lobbia Pass, precisely from the altar (3,025 m a.s.l.) to the top (3,196 m a.s.l.), and extends to the east ridge down to 3,090 m a.s.l. (Fig. 1). The lower part of the southern slope, excluded from the investigated area, is characterized by rocks and boulders with little alteration on the surface, and with very scarce plant colonization.

Analysis of Arietti's "Florula della Lobbia Alta" (1936)

The herbarium of Nino Arietti, kept at the Civic Museum of Natural Sciences of Brescia (HBBS, Thiers 2022), has been catalogued and published (Tagliaferri and Bona 2006). His collections range from 1931 to 1978 (Tagliaferri and Bona 2006)

and the "Florula della Lobbia Alta" is his first scientific publication (La Redazione di Natura Bresciana 1979). Arietti (1936) described his floristic survey of the Lobbia Alta as a "list which, although limited to the product of the observations of a few days, can almost entirely include the local Florula". Clearly Arietti was staying at the Caduti dell'Adamello Refuge for mountaineering reasons and was able to study the flora of the summit just above the refuge. Arietti's list consists of 16 species. In his herbarium there are 12 samples collected here, five of which determined by the eminent botanist Adriano Fiori. Of these 12 samples, however, one does not appear in the Florula, namely *Festuca intercedens* (Hack.) Lüdi ex Bech.; it is a critical species that was determined by Fiori as *F. halleri* All. and then by Rossi and Foggi in 2006 who, more precisely, referred it to *F. intercedens*. By also considering *F. intercedens*, the total number of species detected by Arietti on Lobbia Alta is 17. Doubts still exist regarding two of the five species without herbarium samples, namely *Myosotis alpestris* F.W.Schmidt and *Saxifraga seguieri* Biehler. We presume that they are *Eritrichium nanum* (L.) Schrad. ex Gaudin subsp. *nanum* and *Saxifraga exarata* Vill. subsp. *exarata*, respectively, both common on the top of Lobbia Alta; we attribute Arietti's error to his as yet scarce floristic experience.

Data collection

In all of our three surveys (1991, 2006 and 2021), the entire area (Fig. 1) was carefully explored with the aim of drawing up the most complete inventory possible of the species present. In the last survey (2021) occurrences were geolocalized using the smartphone application described by Andreatta et al. (2017) with the aim of recording accurate maximum elevations reached by the species. The average localization error given by the instrument was ±2.3 m. The elevation was deduced from the coordinates using the digital terrain model. The elevation error, considering the inclination of the area, should not exceed the localization error.

The sampling effort of our surveys was as follows: on 25 August 1991, Lobbia Alta was visited by one of the authors of this paper (FP) and three operators; we estimate that the survey took about 6 hours. On 23 August 2006 it was investigated by two of the authors of this paper (AB and FP) and five operators (Prosser 1997); they dedicated 5 hours to the survey (Prosser et al. 2008). On 26 August 2021 two of the authors (AB and GT) repeated the survey in 4 hours, therefore with a minor sampling effort (see Burg et al. 2015).

Biological forms follow Pignatti et al. (2017–2019). Temperature and nutrient indexes of the species follow Ellenberg et al. (2001) with few integrations with Pignatti (2005). Nomenclature follows Bartolucci et al. (2018) and subsequent updates (Portal to the Flora of Italy 2022+). The elevation records were first verified at the local level, on the basis of "Flora del Trentino" (Prosser et al. 2019), then at the alpine and, sometimes, European level, referring to databases available on the web (e.g., GBIF 2022; Infoflora 2022+), bibliographic data (see references) and other information obtained from botanists interested in summit flora were also used.

Results and discussion

The number of species surveyed on Lobbia Alta in 86 years has risen from 17 to 55 (Suppl. material 1), of which however four, recorded in 2006, were not found in 2021. The variation in the number of species over time and the variation of biological forms are shown in Fig. 2.

Variability of the temperature index and nutrients index for each survey are shown in Figs 3, 4, respectively.

In the period 1935–1991, the number of species grew from 17 to 36 (Suppl. material 1). No species disappeared. The entry rate was 0.34 species / year. Some of the species not detected by Arietti were quite widespread in 1991: this is the case, for example, of *Facchinia herniarioides* (Rion) Dillenb. & Kadereit and *Primula daonensis* (Leyb.) Leyb. The biological spectrum becomes more complex with the entry of the first therophyte (*Euphrasia minima* Jacq. ex DC.) alongside hemicryptophytes and chamaephytes. The first fruticose chamaephyte is *Vaccinium uliginosum* L. subsp. *microphyllum* (Lange) Tolm.; its presence is clearly excluded by Arietti (1936): "shrubs

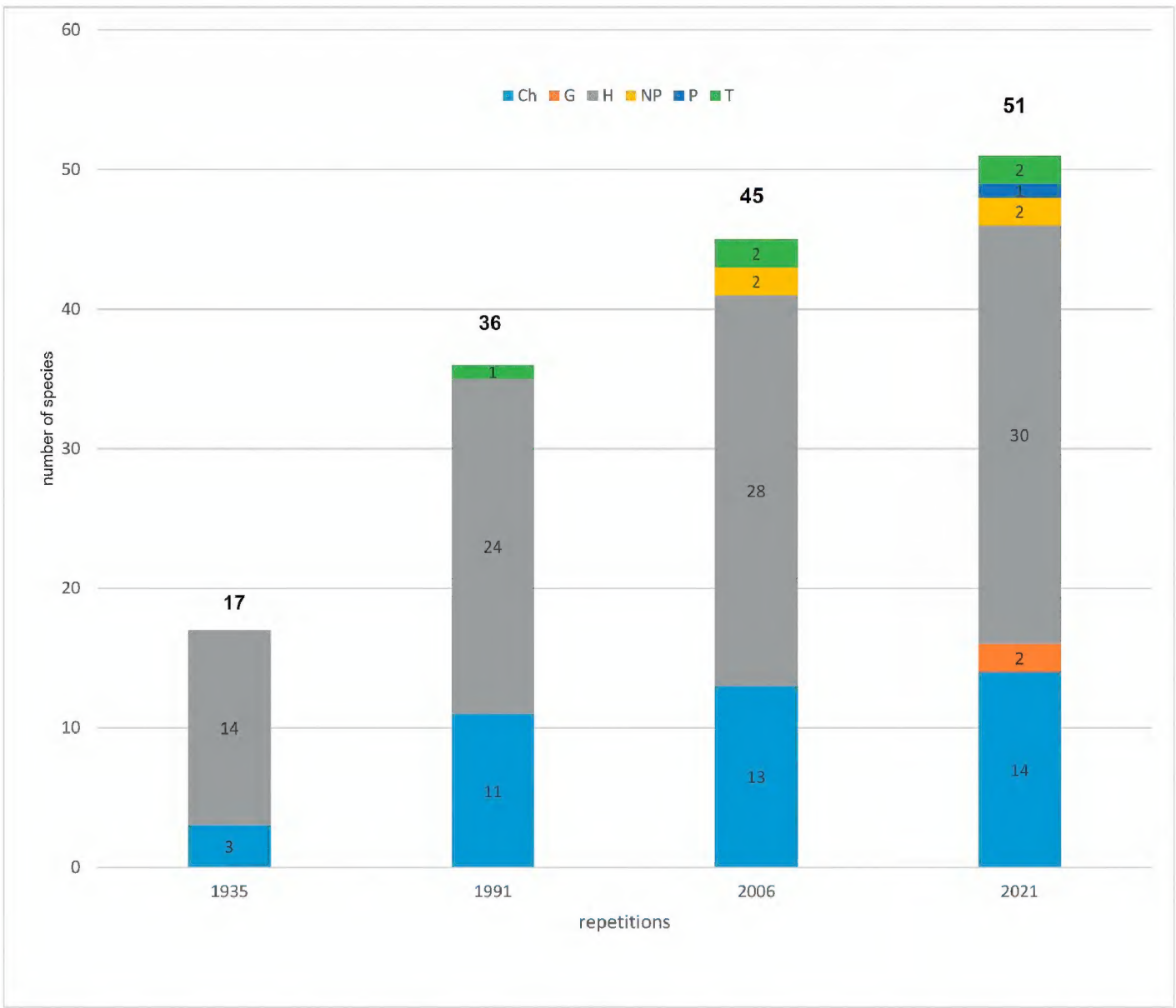

Figure 2. Variation over time of the flora of the Lobbia Alta with biological spectra (Ch: Chamaephytes; G: Geophytes; H: Hemicryptophytes; NP: Nanophanerophytes; P: Phanerophytes; T: Therophytes).

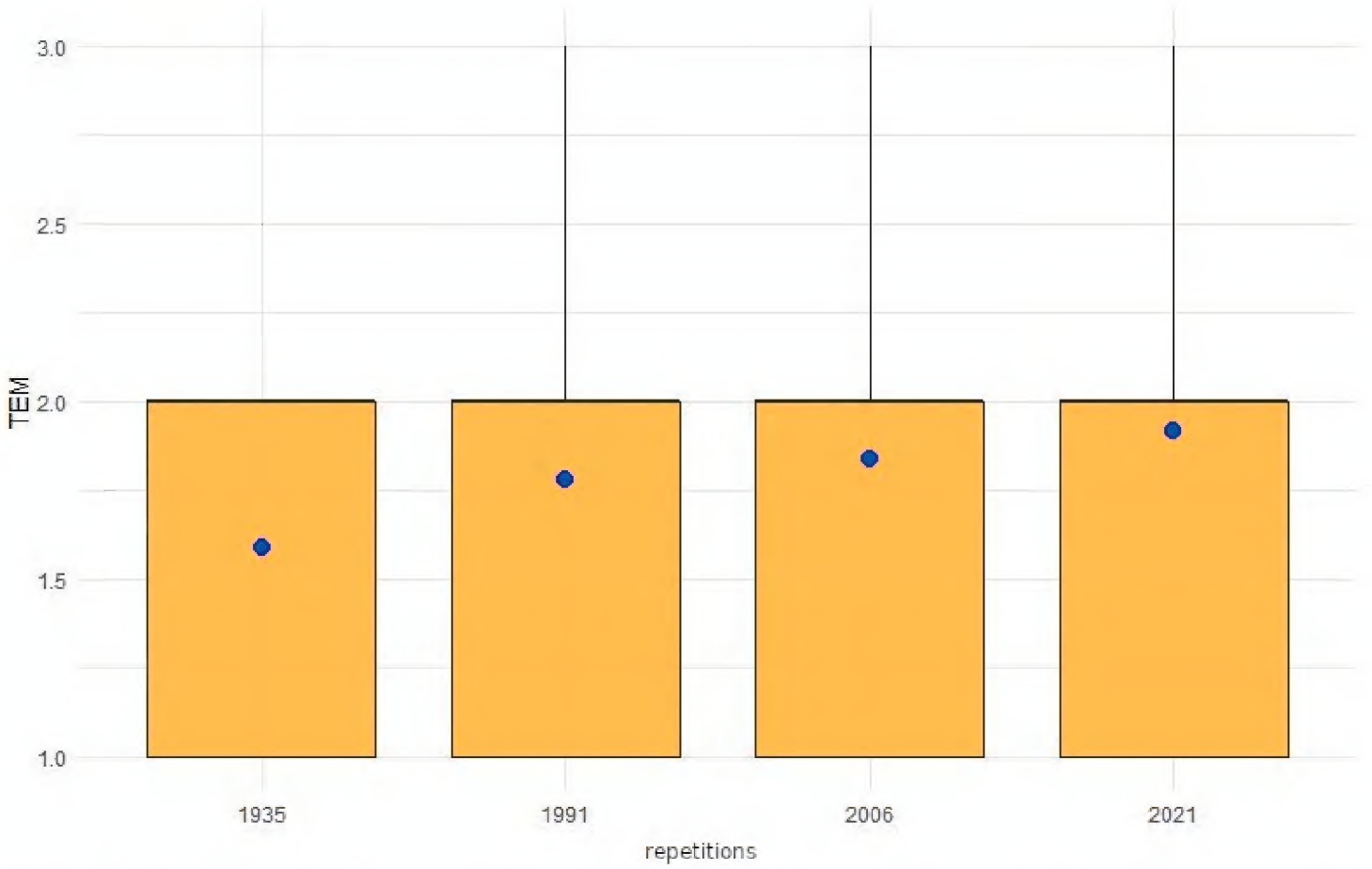

Figure 3. Variability of temperature index (TEM) according to Ellenberg et al. (2001) with indication of mean (blue dot) and of median (black line).

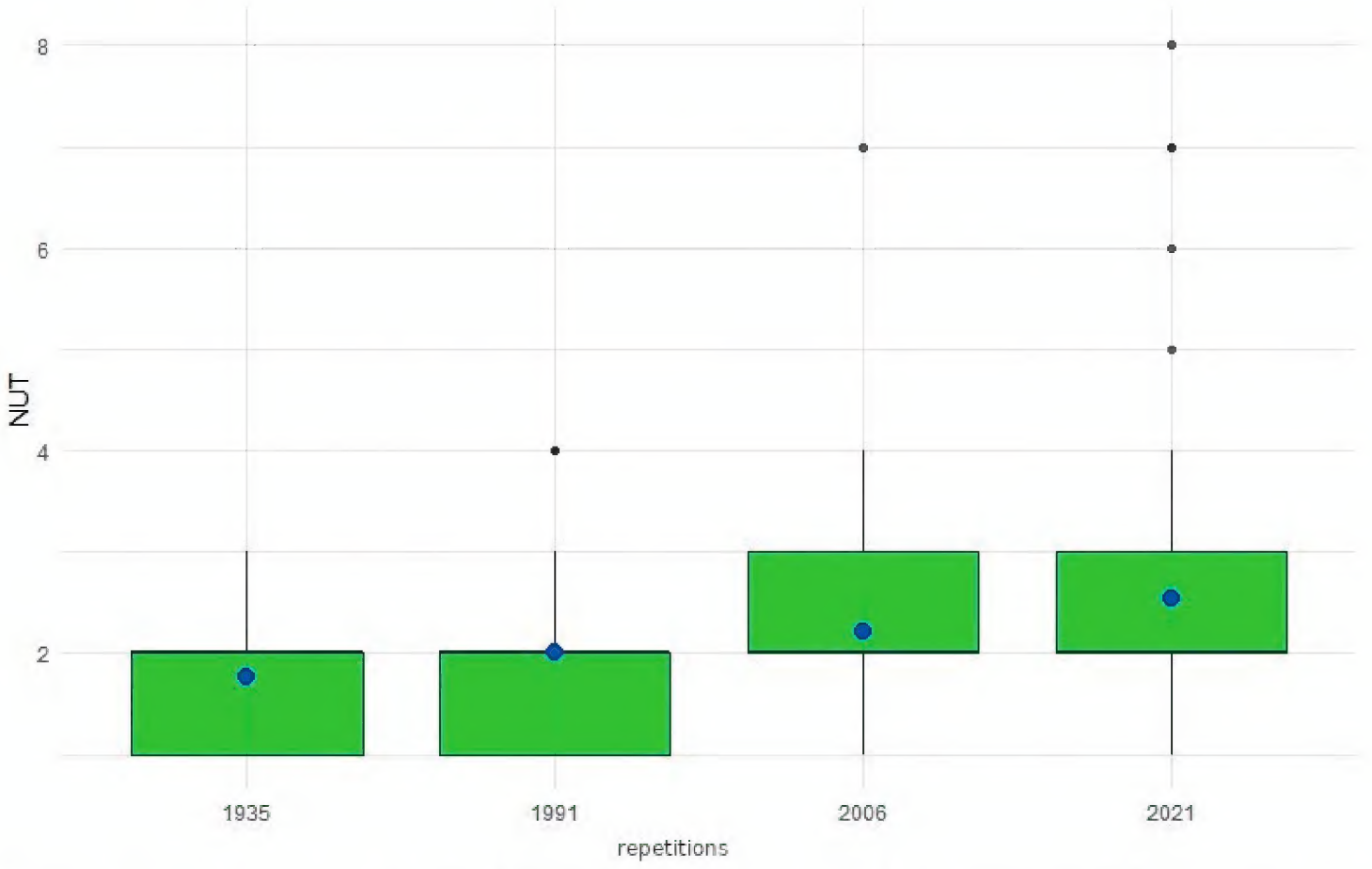

Figure 4. Variability of nutrients index (NUT) according to Ellenberg et al. (2001) with indication of mean (blue dot) and of median (black line).

are completely missing, including fruticose and suffruticose". The average temperature index (Fig. 3) and the nutrient index (Fig. 4) increased by about 0.2 points.

In the period 1991–2006, the number of species rose to 45 with the confirmation of all the species surveyed in 1991 (Suppl. material 1). The entry rate increased to 0.6 species / year, values compatible with those reported for European mountain regions by Steinbauer et al. (2018). Among the nine additional species, there are the first woody ones: *Juniperus communis* L., *Rhododendron ferrugineum* L., and *Salix herbacea* L. The first two are classified as nanophanerophytes, and this biological form adds to the spectrum (Fig. 2). The temperature and the nutrient indices rose slightly in that period (Figs 3, 4).

In the period 2006–2021, the total number of species rose to 51, with an entry rate of 0.4 species / year. As many as 10 species were found for the first time; however, compared to 2006, four species are not confirmed (*Potentilla frigida* Vill., *Rhododendron ferrugineum*, *Salix herbacea* and *Solidago virgaurea* L. subsp. *minuta* (L.) Arcang.). The first phanerophyte, *Larix decidua* Mill., and the first geophytes, *Agrostis schraderiana* Bech. and *Coeloglossum viride* (L.) Hartm., appear. Among the nanophanerophytes, *R. ferrugineum* is not confirmed, but *Salix helvetica* Vill. appears. Furthermore, among the fruticose chamaephytes, the lack of confirmation of *S. herbacea* is compensated by the addition of *Empetrum hermaphroditum* Hagerup. The temperature index approaches 2 (Fig. 3) due to the entry of thermophilic species. A similar trend is shown by the nutrients index (Fig. 4) due to the entry of nitrophilous species (e.g., *Cirsium spinosissimum* (L.) Scop.).

The elevations recorded in the 2021 survey show that for about 20 species the elevation record published in "Flora del Trentino" had been exceeded (Prosser et al. 2019). The following species would seem to set an elevational record at least at the alpine level.

Coeloglossum viride, a circumboreal species present at 3,150 m a.s.l. on the Lobbia Alta, is probably the highest known orchid in Europe, including the Caucasus (Bertolli et al. 2021).

Gentiana nivalis L., a species widespread mainly in the European mountains, was found at 3,123 m on the Lobbia Alta, just above the known elevations in the Alps. The second known record is 3,110 m in Val di Cogne in the Pousset valley (2001, Poggio and Gerard in Flora della Valle d'Aosta 2022+), but already Fenaroli (1955) indicated it in the Alps up to 3,100 m. For the Caucasus, there is a record at *ca.* 3,145 m in August 2018 by D.S. Shilnikov (iNaturalist 2022+).

Gentianella anisodonta (Borbás) Á.Löve & D.Löve, an endemic species to the eastern Alps, found at 3,145 m on the Lobbia Alta, is most likely the record for the elevation of the species. Braun-Blanquet and Rübel (1932–1935) indicate it in the Grisons (Switzerland) up to 2,780 m.

We found a 35-cm tall specimen of *Larix decidua* on Lobbia Alta (Fig. 5) at 3,130 m and it seems to be the elevation record of the species. The previous maximum elevation that we have been able to trace for this species is 2,995 m in the French Alps (Gilles André, personal communication). Other notable finds are at 2.990 m on Cima Paier in the Adamello-Presanella Alps (1991, Bronzini and Prosser,

Figure 5. A specimen of *Larix decidua* photographed at 3,130 m near the summit of Lobbia Alta (Trento, Italy). Currently it may be the elevation record of the species (photo GT).

archive of the flora of Trentino of the Civic Museum of Rovereto), at 2,971 m in Switzerland (Wiwannihorn, Ausserberg), where, in 2015, Egon Feller found a 21-cm tall specimen (Swiss National Forest Inventory 2022+), and the one at 2,970 m for Las Sours by Anders Björken (Wifp, personal communication). Fenaroli (1955) gave a maximum elevation for the Alps of 2,660 m. The record for the highest tree in the Alps (and in Europe) is *Pinus cembra* found by Andrè (2016) at 3,200 m on the Italian side of Monte Viso: it is a 1.1-m tall specimen in a rocky position. The larch found on Lobbia Alta is the second highest tree in the Alps and in Europe. In the Caucasus, it seems that trees do not grow beyond 3,100 m (Dolukhanov 1978; Gigauri, personal communication).

Primula daonensis, an endemic species to a small sector of the eastern Alps, was found up to 3,151 m on the Lobbia Alta; it confirms an earlier record for the species, which was always on the Lobbia Alta at 3,110 m (Prosser et al. 2019). Previously, the elevation record of the species was indicated by Becherer (1976) at 2,960 m on Piz Rims in Val Müstair (obs. Nicolin Bischoff, 04/07/1975). Fenaroli (1955) indicated it in the Alps up to "2,800 (2,900?) m".

Salix helvetica, a species with alpine distribution, was found at 3,111 m on the Lobbia Alta, but the specimen is little more than a seedling. The second highest record is at 3,010 m in Val di Cogne, under the Lauson glacier (Mainetti et al. 2016 in Flora della Valle d'Aosta 2022+). The highest record for Switzerland by Infoflora (2022+) is 2,919–2,922 m at Saas-Grund (obs. Jasmin Ducry, 04/08/2017). Fenaroli (1955) indicated it in the Alps up to 3,000 m.

Conclusions

Our results are in agreement with the general trend of enrichment of the flora of the high alpine peaks. Various species have managed to reach the Lobbia Alta, despite being a rather isolated peak surrounded by ice and inhospitable cliffs. Seed dispersal by wind (e.g., *Larix decidua*) and birds (e.g., *Empetrum hermaphroditum*) has made it possible to colonize these peaks. More and more often, seedlings and saplings find suitable conditions for their establishment due to the increasingly longer period without snow, consequent to climate warming. Lobbia Alta, and in particular its southern side, appears suitable for the settlement of species from lower elevations, as shown by elevation records also for some species that are widespread in the western Alps (*Gentiana nivalis*, *Larix decidua*, *Salix helvetica*) where, due to the mass effect, species usually reach their highest elevation in the Alps (see e.g., Ellenberg 1996). It seems surprising to find as many as six alpine elevation records on a single peak of the Alps. It could even be hypothesized that the southern Rhaetian Alps are subject to a more intense upwelling of species due to climate warming than other Alpine areas. Further research is needed to test this hypothesis.

In 2021, the presence of some species, recorded after 1935, has not been confirmed, i.e., *Potentilla frigida*, *Rhododendron ferrugineum*, *Salix herbacea*, and *Solidago virgaurea* subsp. *minuta*; this would suggest that the colonization process is not linear, but is "trial and error". On a peak of more than 3,000 m a.s.l. such as Lobbia Alta, it is the newcomers who are more likely to disappear, rather than the species that have been established there since a long time. Nonetheless, the latter could also be undermined by further global warming.

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Supplementary material 1

Floristic occurrences of the flora of the Lobbia Alta (Trento, Italy) between 1935 and 2021

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Data type: table (excel file)

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